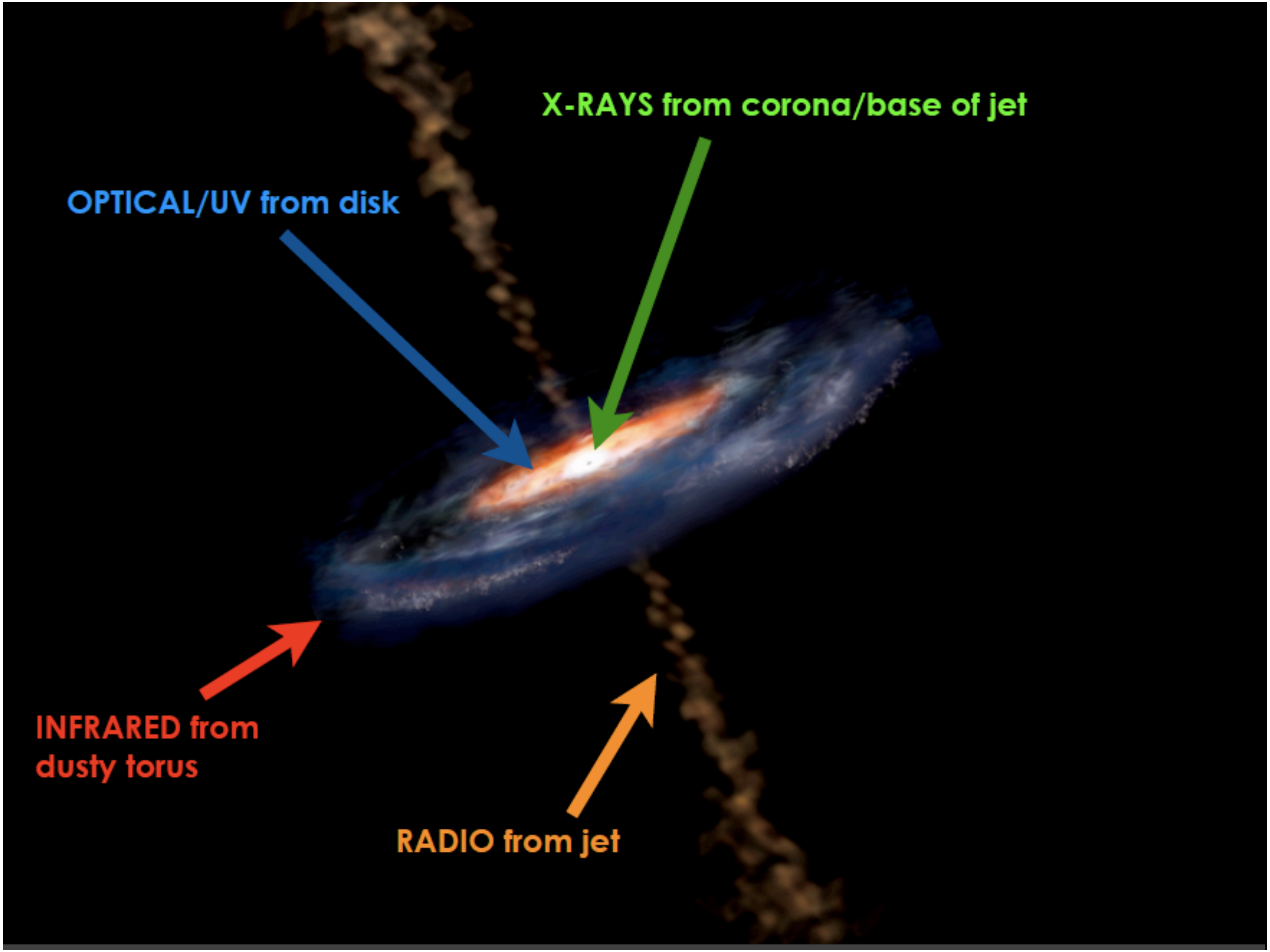
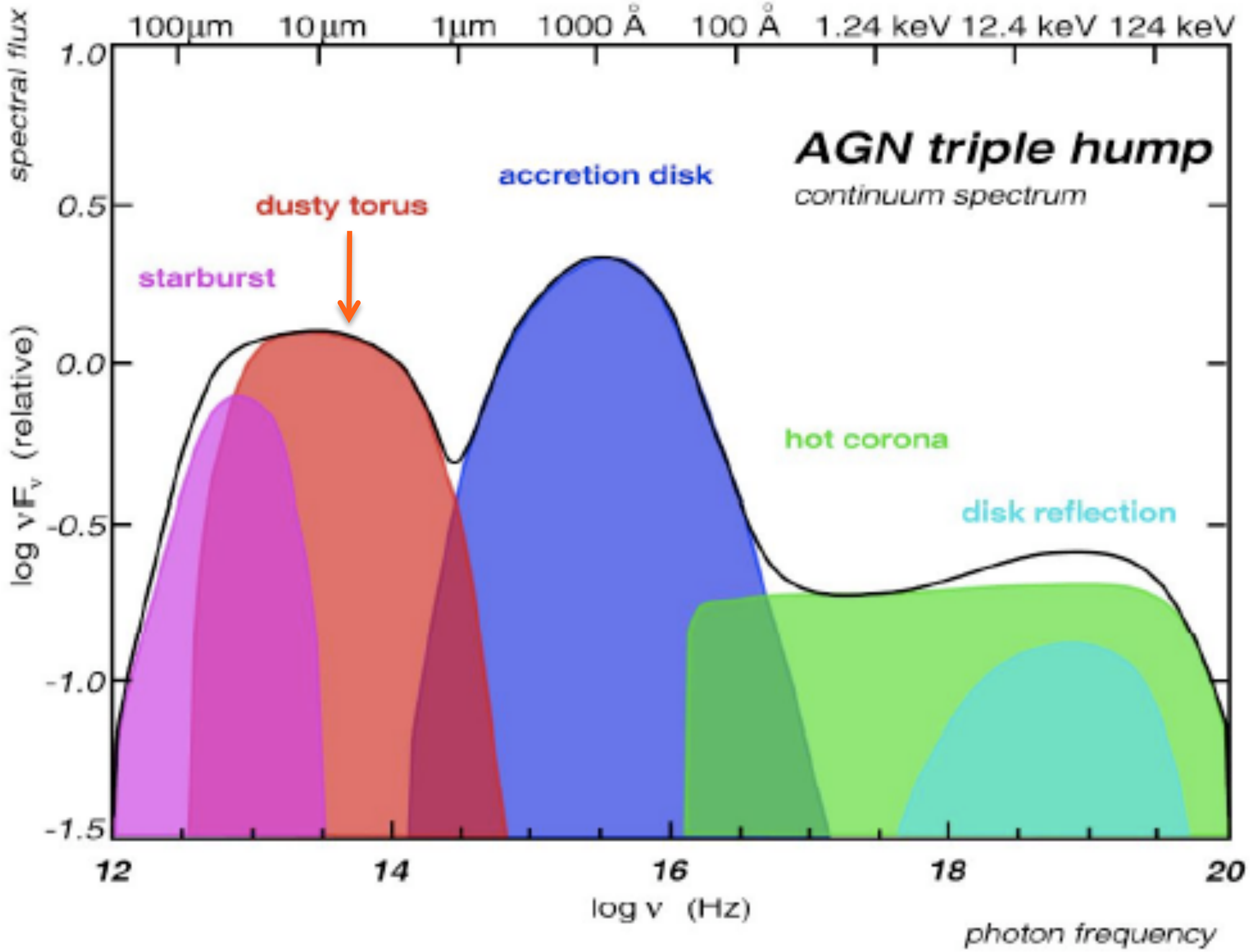
Active Galactic Nuclei − IV

Mid-IR emission from AGN and the quest for heavily obscured AGN

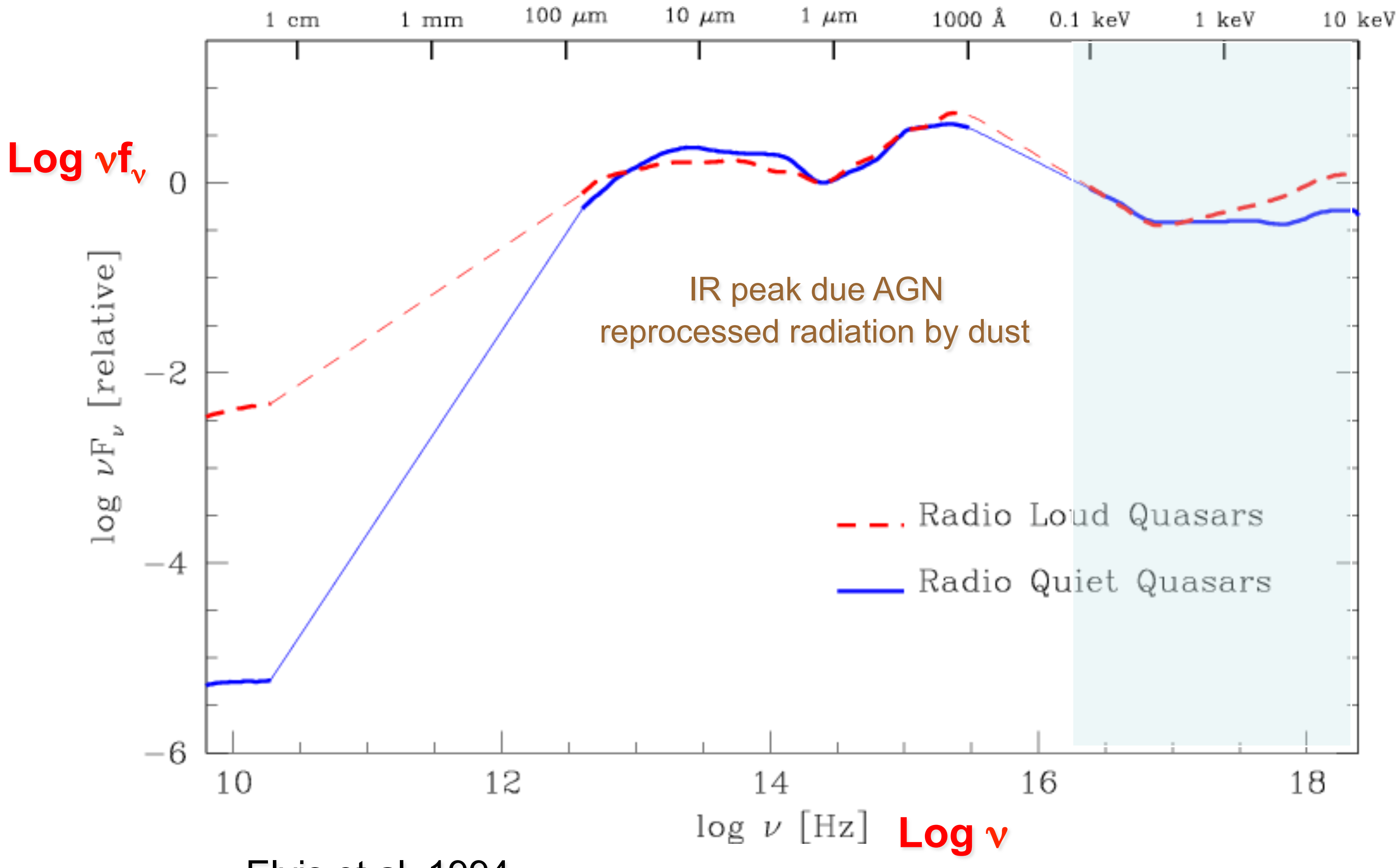
AGN Spectral Energy Distributions


X-RAYS from corona/base of jet
OPTICAL/UV from disk
INFRARED from
dusty torus
RADIO from jet

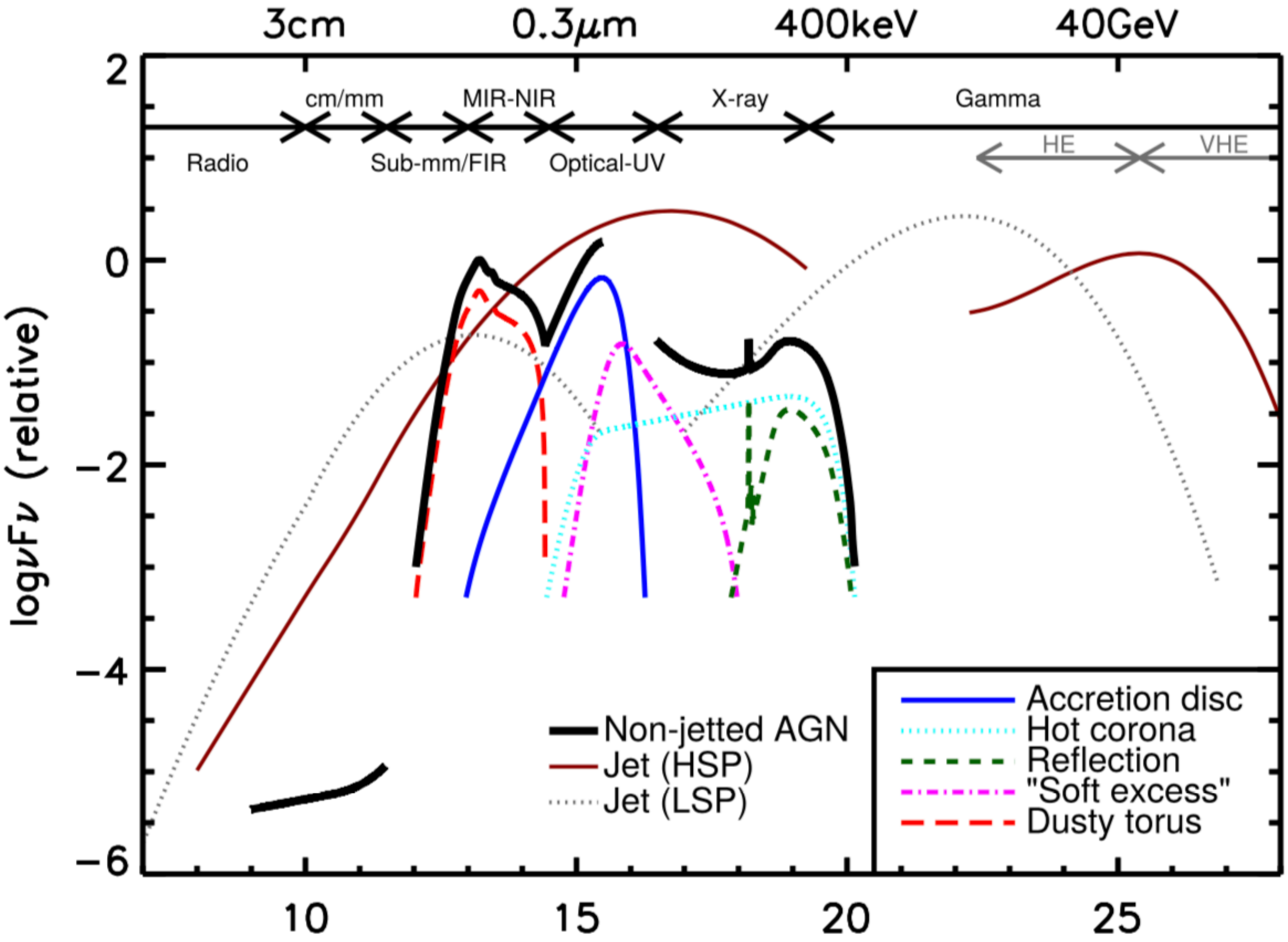


100µm
10µm
1µm
1000 Å
100 Å
1.24 keV
12.4 keV
124 keV
spectral flux
1.0
0.5
0.0
-0.5
-1.0
-1.5
log νF$_ν$ (relative)
AGN triple hump
continuum spectrum
accretion disk
dusty torus
starburst
hot corona
disk reflection
12
14
16
18
20
log ν (Hz)
photon frequency

Broad-band spectral energy distribution of AGN



Elvis et al. 1994



adapted from Harrison (2014)

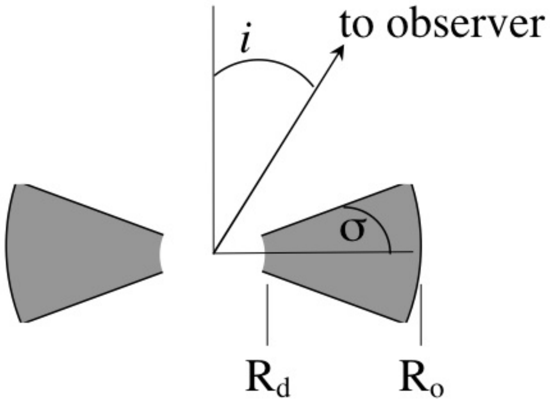
HSP: high synchrotron peak blazar
LSP: low synchrotron peak blazar

Mid-IR emission from AGN

Models for the infrared emission of AGN (I)

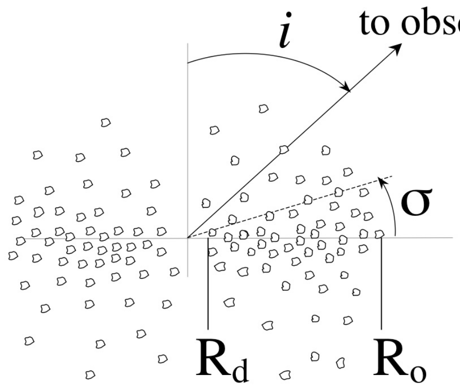
Smooth dust distribution

dust grains around a central source (AGN) in a smooth distribution (e.g., Pier & Krolik '92, '93)



Clumpy models

dust grains in clouds (not uniform distribution) A Type 2 AGN can be seen also at large inclination angles over the equatorial plane (e.g., Nenkova et al. '02, '08)

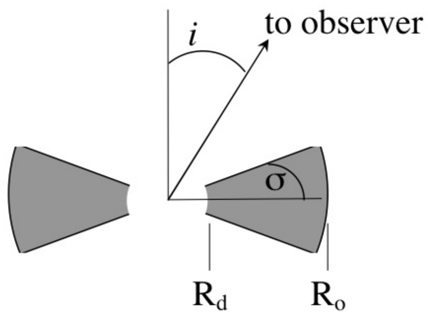


Models for the infrared emission of AGN (II)

Smooth dust distribution: main properties

• The source is obscured if radiation intercepts the torus, hence obscuration is related to geometrical issues

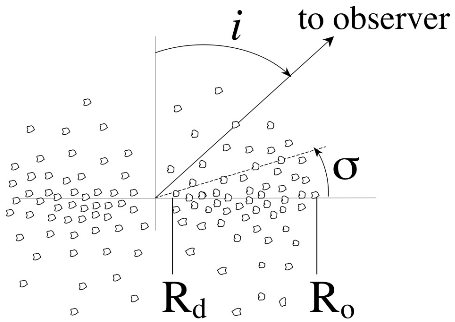
• Dust temperature is a function of the distance from the source of the radiation field



Clumpy models: main properties

• The probability of direct viewing of the AGN decreses away from the axis, but is always finite

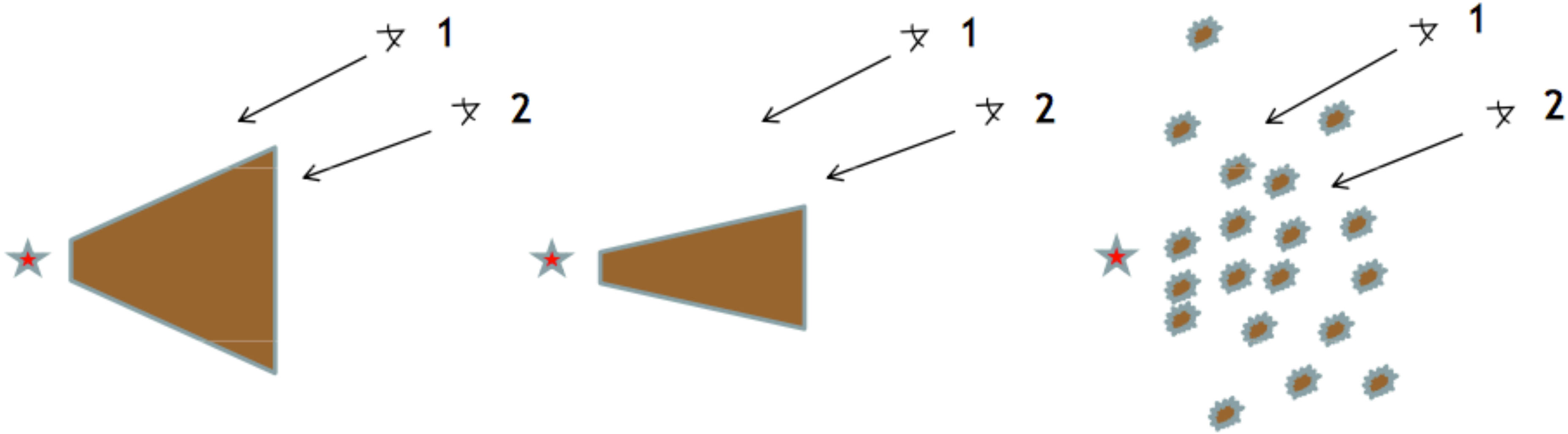
• Different dust temperatures coexist at the same distance from the radiation source, and the same dust temperature occurs at different distances



AGN type is a viewing-dependent probability

Alternative modeling: hydromagnetic disk wind

• Torus=toroidal region of a wind, structured in outflowing clouds. The acceleration is provided by magnetic field lines anchored in the disc (Blandford & Payne ‘82; Elitzur ‘08)



Smooth-density torus Torus with decreased covering factor Clumpy, soft-edge torus

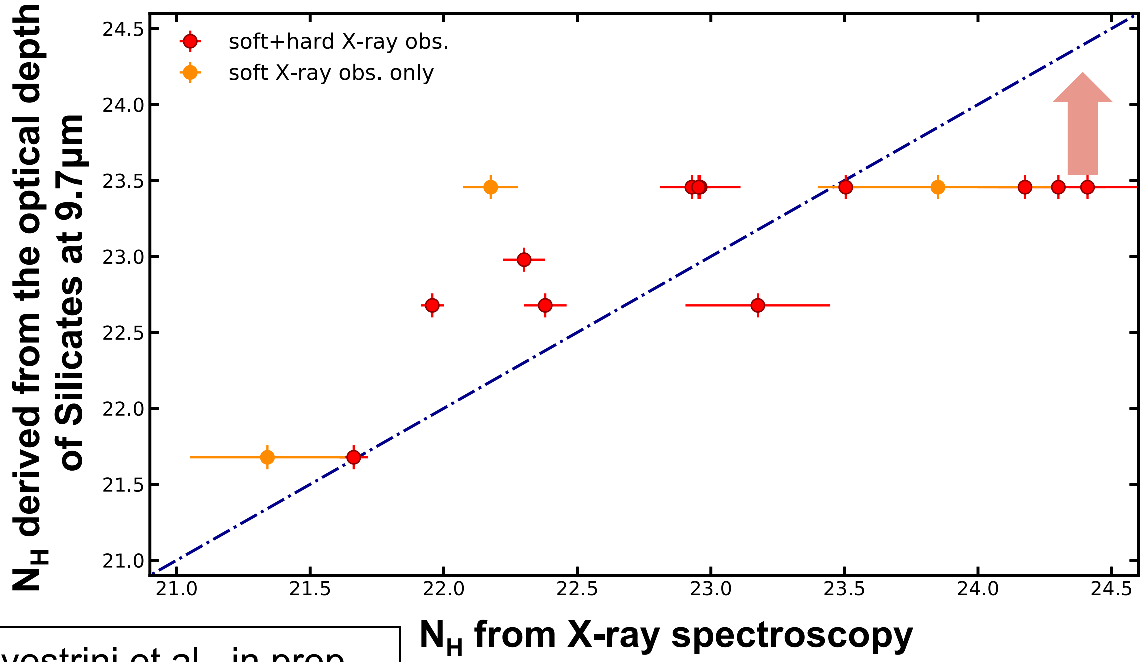
The covering factor can be estimated using
SED fitting with multiple (host galaxy and AGN) components
(but model degeneracies may affect the results)

Elitzur 2011

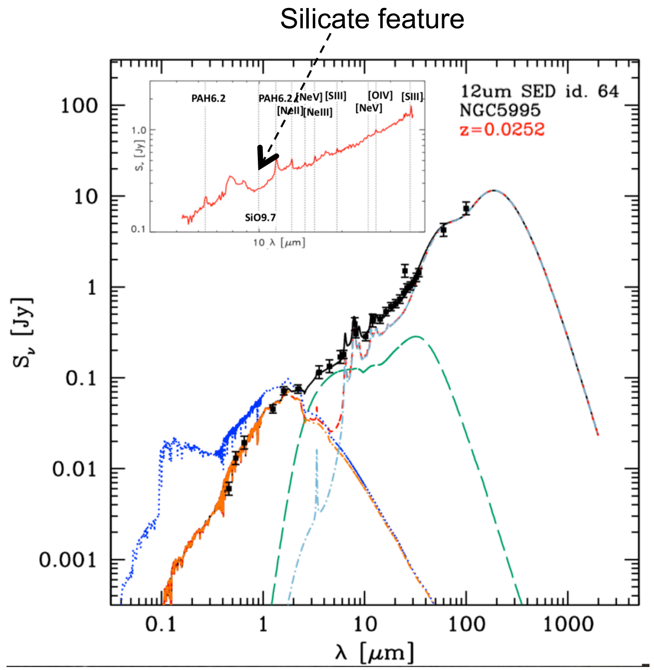
Currently: attempts to link the properties of the absorber derived from X-rays with those of mid-IR and SED analysis in a systematic way

Deep Silicate features vs. heavy X-ray obscuration

IRAS-12μm sample of Type 2 AGN with *Spitzer*/IRS coverage



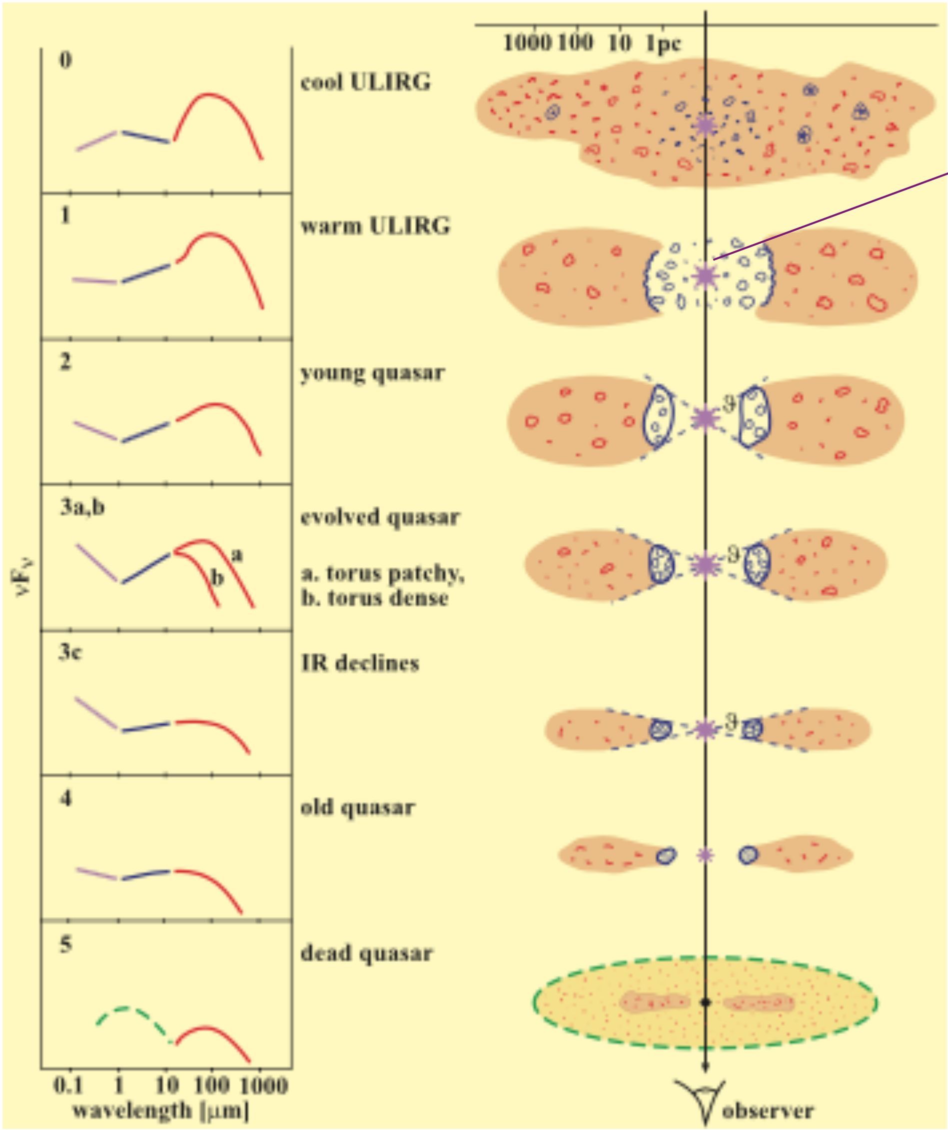
Salvestrini et al., in prep.



Systematic multi-wavelength study of IRAS 12-micron sample (X-ray, SED fitting, molecular gas content, gas kinematics, etc.)

Effects of the AGN on the host galaxy

see also Alonso-Herrero+ works, Mateos et al. 2016, […]



AGN strength

The dust re-arranges during the AGN history.

The SED displays these changes

Haas et al. 2003

Indications from X-ray observations of local Seyferts that absorbers can be structured in clumps

Eclipses of the X-ray source are COMMON in nearby AGN: $\Delta N_H \sim 10^{23}$–10^{24} cm^{-2}

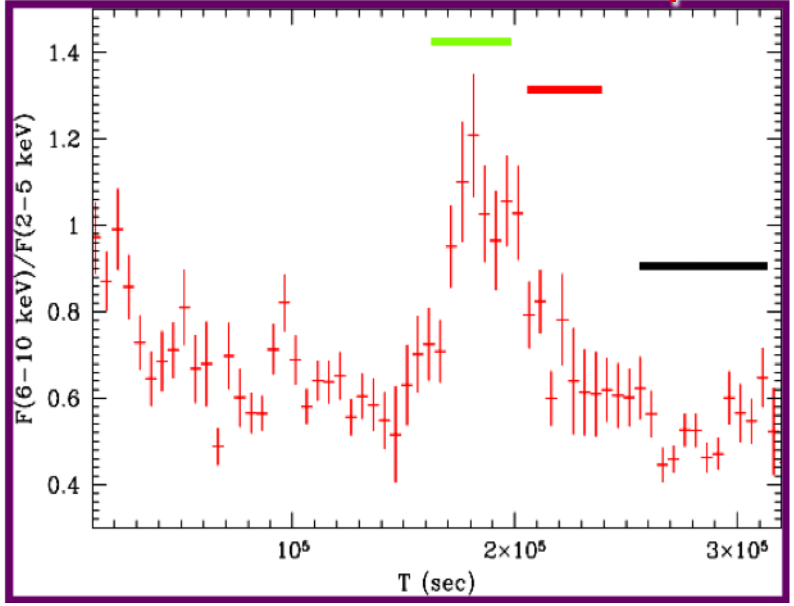
↓

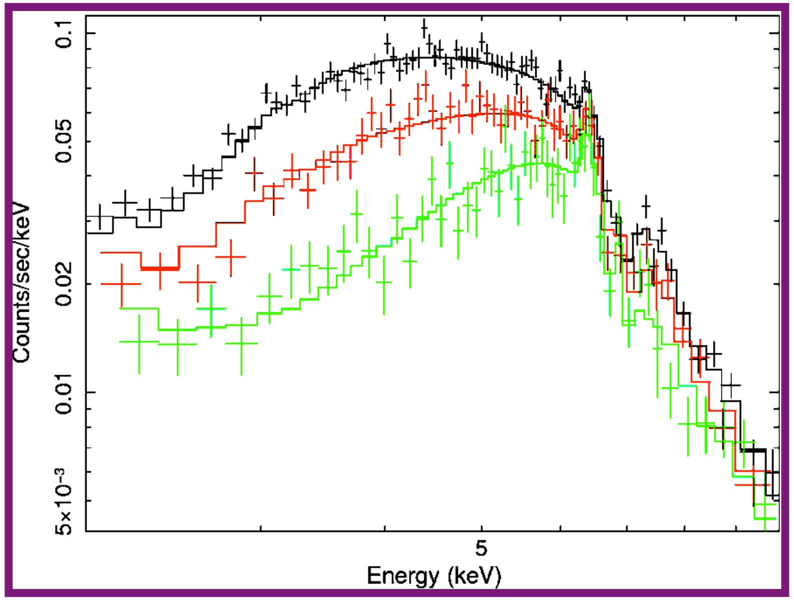
size X-ray src $<10^{14}$ cm
D $< 10^{16}$ cm

↓

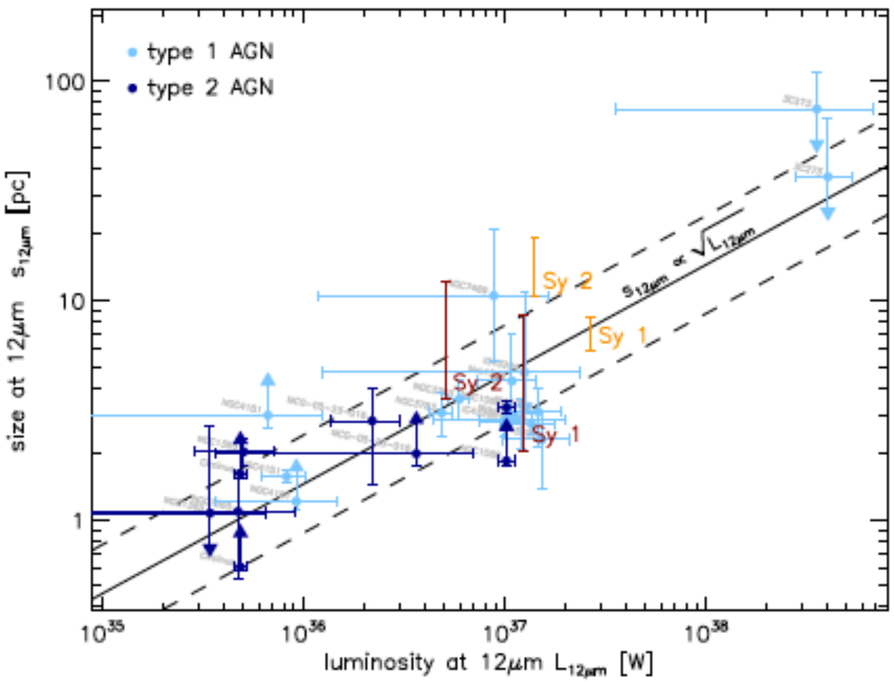
X-ray absorber "made" of BLR clouds

Risaliti et al., 2007, 2010…





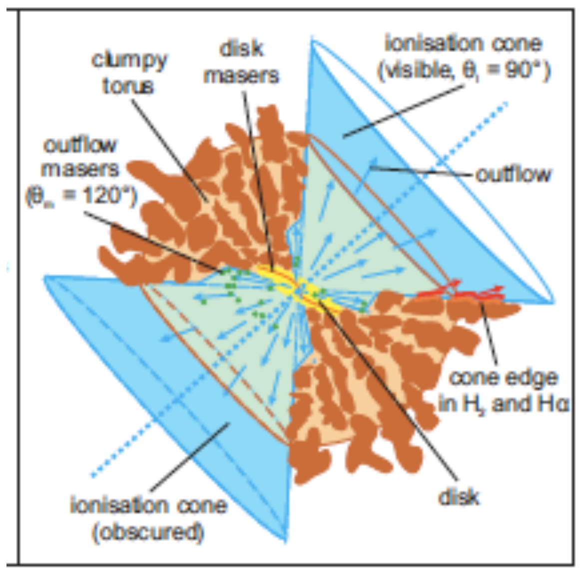
High-resolution mid-IR observations of Seyferts



Tristram & Schartmann 2011
(see also Jaffe+04; Meisenheimer+07; Tristram+07; Tristram+09; Burtscher+13)

- Compact (a few pc) tori with a clumpy/filamentary dust distribution (warm disk + geom. thick torus)

- No significant Sey1/Sey2 difference



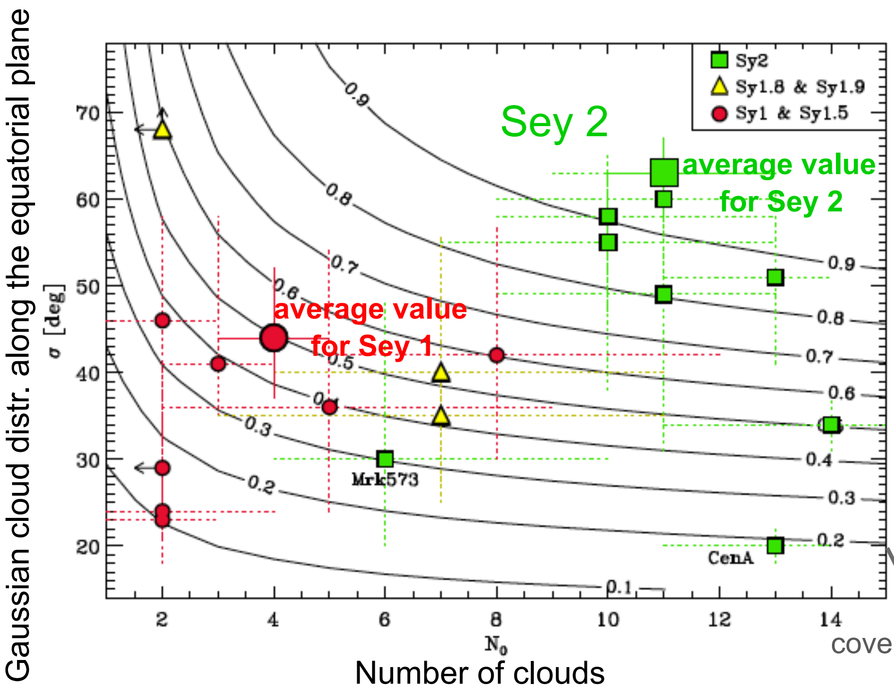
Tristram+07 - Circinus

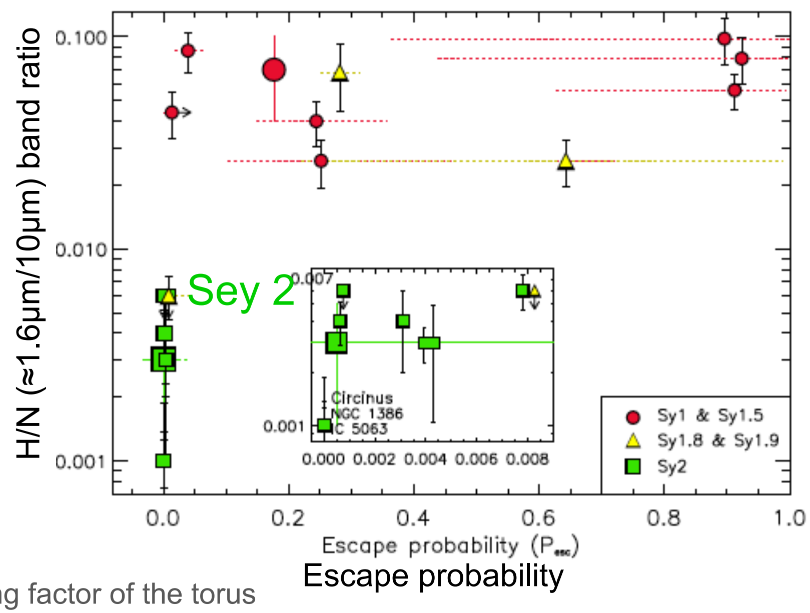
Modeling the mid-IR emission with “clumpy” torus

✓ Type 1 vs. Type 2 AGN difference: it is a function of the number of clouds along the line of sight, i.e., of the escape probability

✓ Same dust temperatures can be observed at different distances from the AGN

➔ Type 2 AGN: larger number of clouds and lower P_{esc} for the photons to escape





covering factor of the torus

Ramos-Almeida+11; see also Garcia-Bernete+19

Mid-IR as a proxy of the nuclear (intrinsic) AGN power

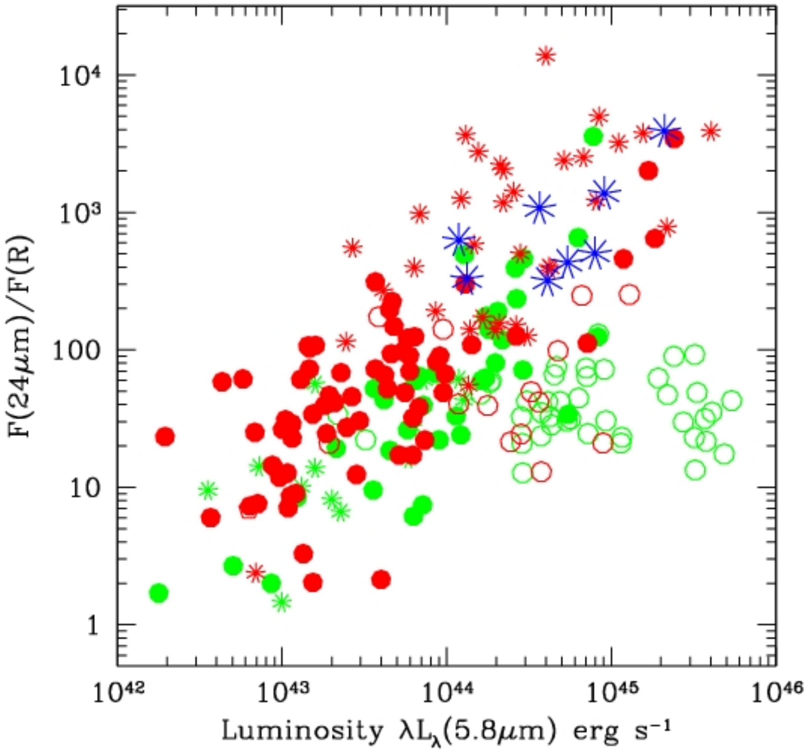
➢ The mid-IR emission is mostly due to reprocessing (i.e., thermalized by dust) of the intrinsic AGN emission.
The UV/optical emission in obscured AGN is extincted but re-emerges as IR emission.

➢ Selecting sources extincted in the UV/optical and bright at mid-IR wavelengths provides a good tool to pick up obscured sources.

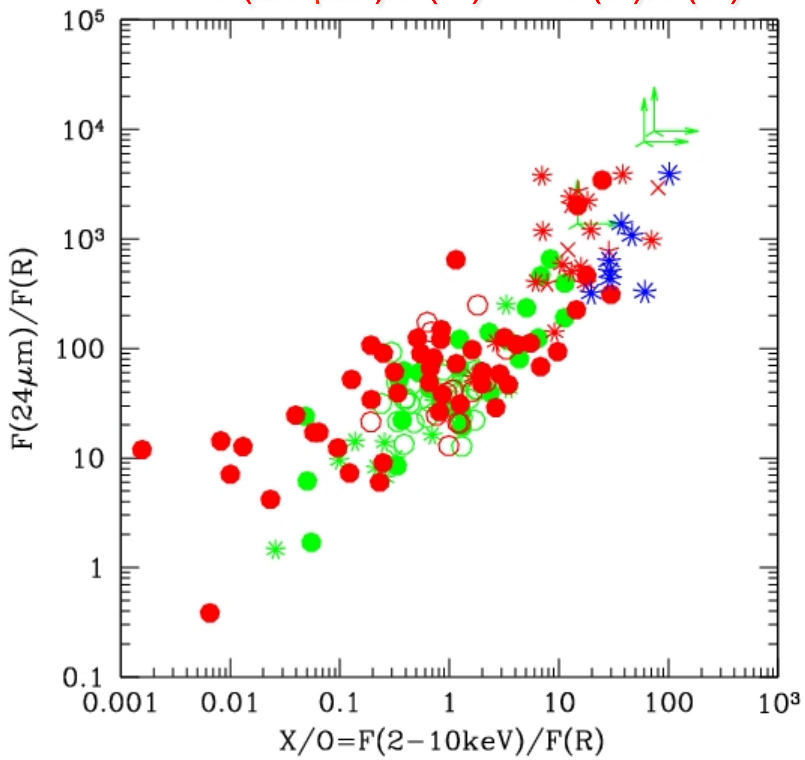
➢ Stacking X-ray emission and consequent comparison with expected X-ray emission provides an estimate on the amount of obscuration.

The combined optical/mid-infrared selection in the quest for Compton-thick AGN at high-z (I)

F(24 μm)/F(R) vs. L(5.8 μm)



F(24 μm)/F(R) vs. F(X)/F(R)

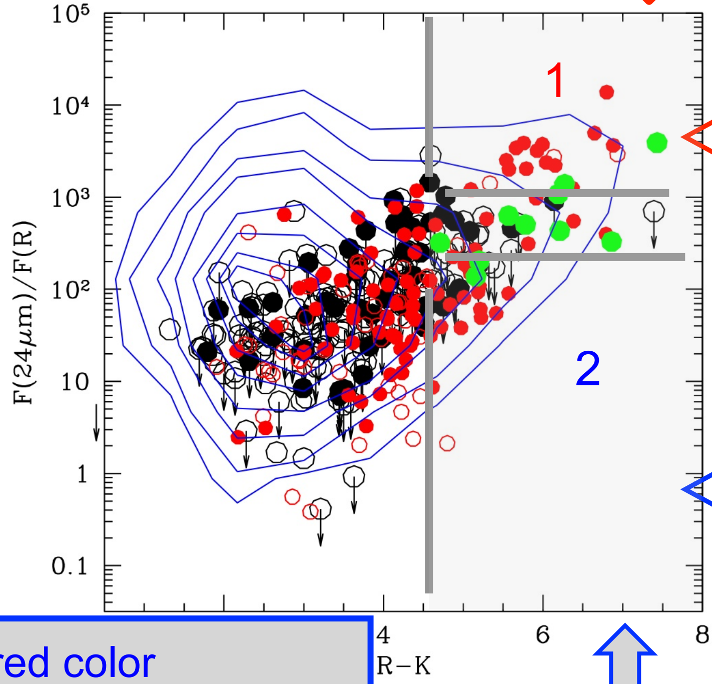


From Fiore et al. (2008)
Different symbols: different surveys
Filled symbols: Type 2 AGN candidates

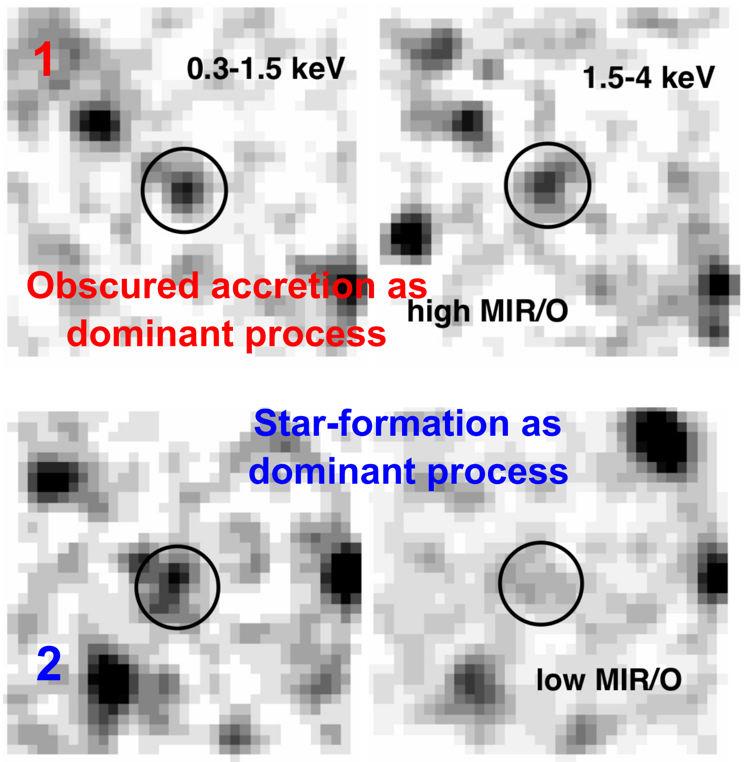
In Type 2 AGN candidates, the **F(24 μm)/F(R)** ratio correlates with **L(5.8 μm)** and **F(X)/F(R)**
➔The MIR luminosity provides an estimate of the X-ray flux

The combined optical/mid-infrared selection in the quest for Compton-thick AGN at high-z (II)

red color
bright at 24µm but faint in the optical



red color
Low 24µm to optical flux ratio



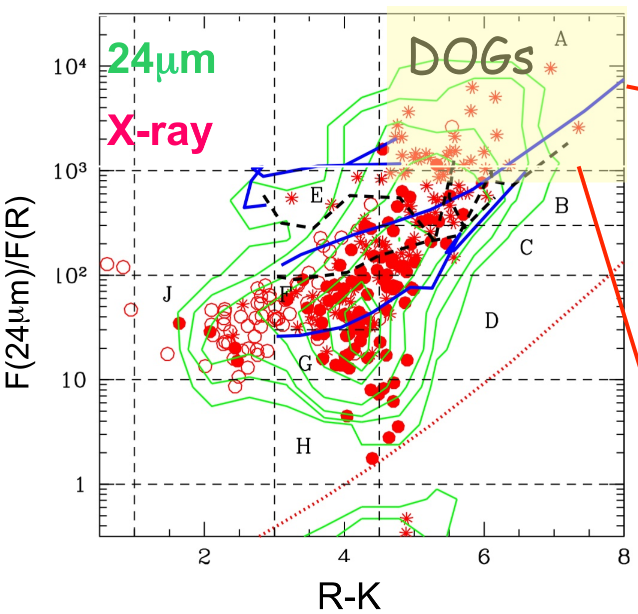
CDF-S: <log L(5.8 µm)> $\approx$ 44.6

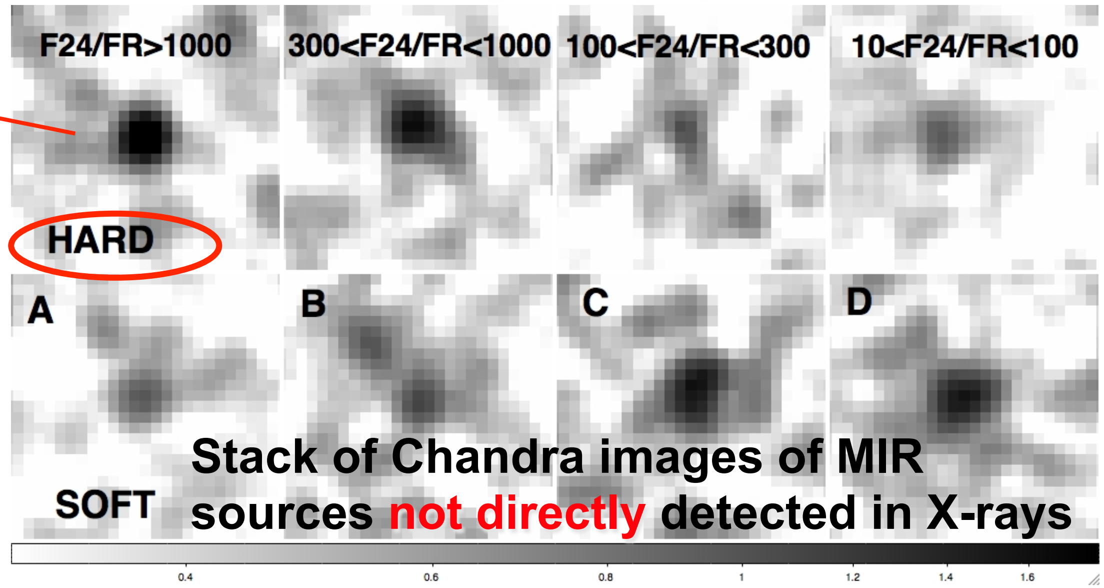
$\mathrm{Log}(L_X) \approx 43$ (expected) vs. 41.8 (observed from X-ray stacking analysis)

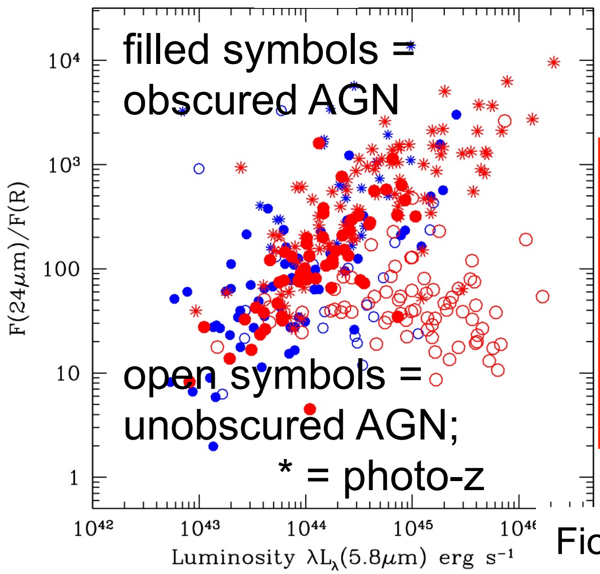
➔Log N_H>24 at the z=2 (Compton-thick)

Fiore et al. 2008

The combined optical/mid-infrared selection in the quest for Compton-thick AGN at high-z (III)

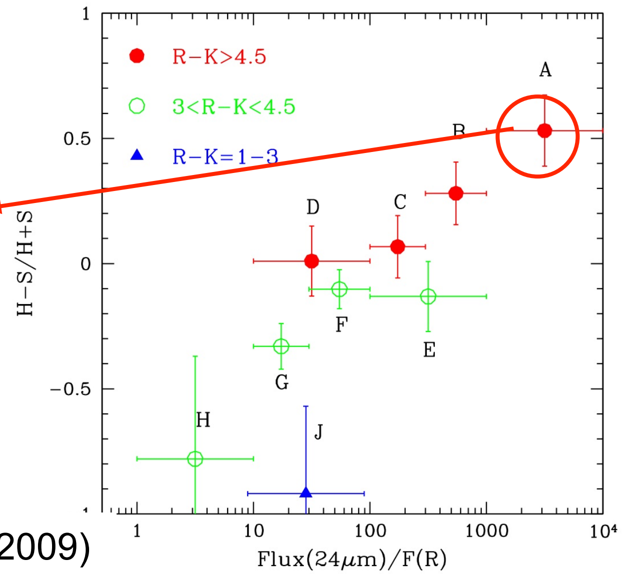






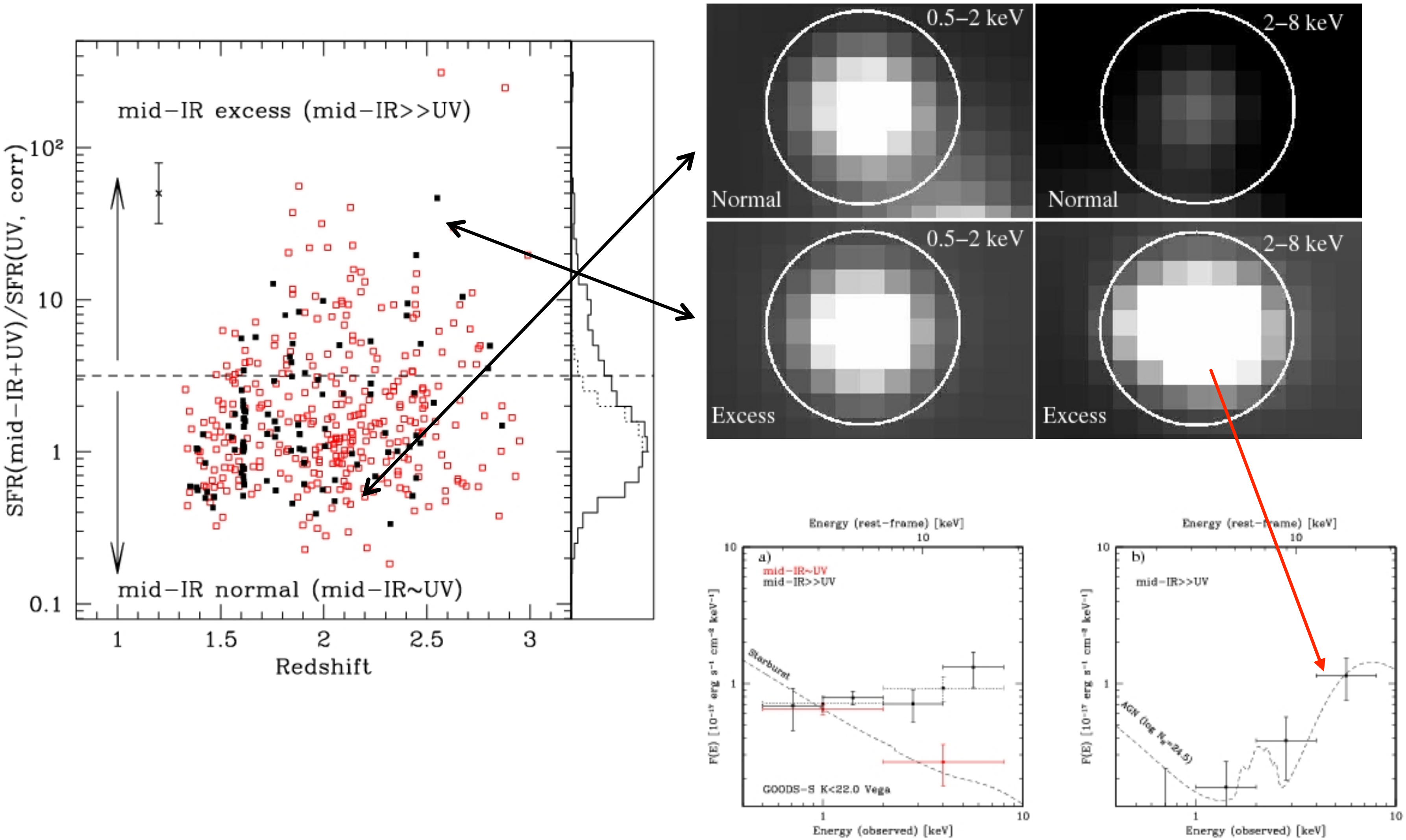
COSMOS:
large fraction of Compton-thick AGN candidates at z≈2 in cell A

Fiore et al. (2009); Lanzuisi et al. (2009)



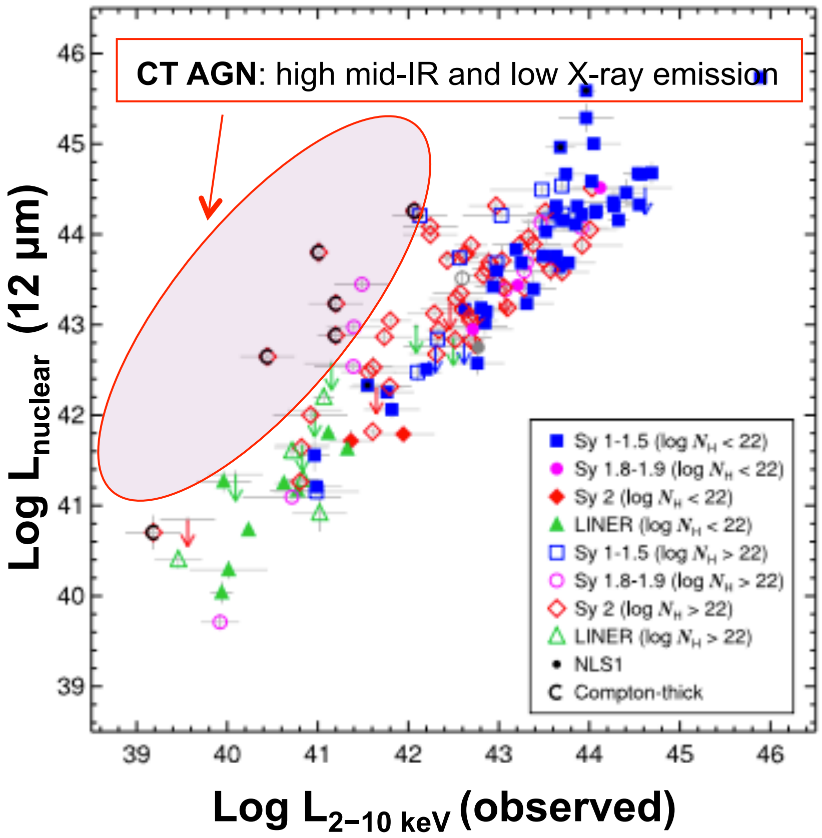
The combined optical/mid-infrared selection in the quest for Compton-thick AGN at high-z (IV)

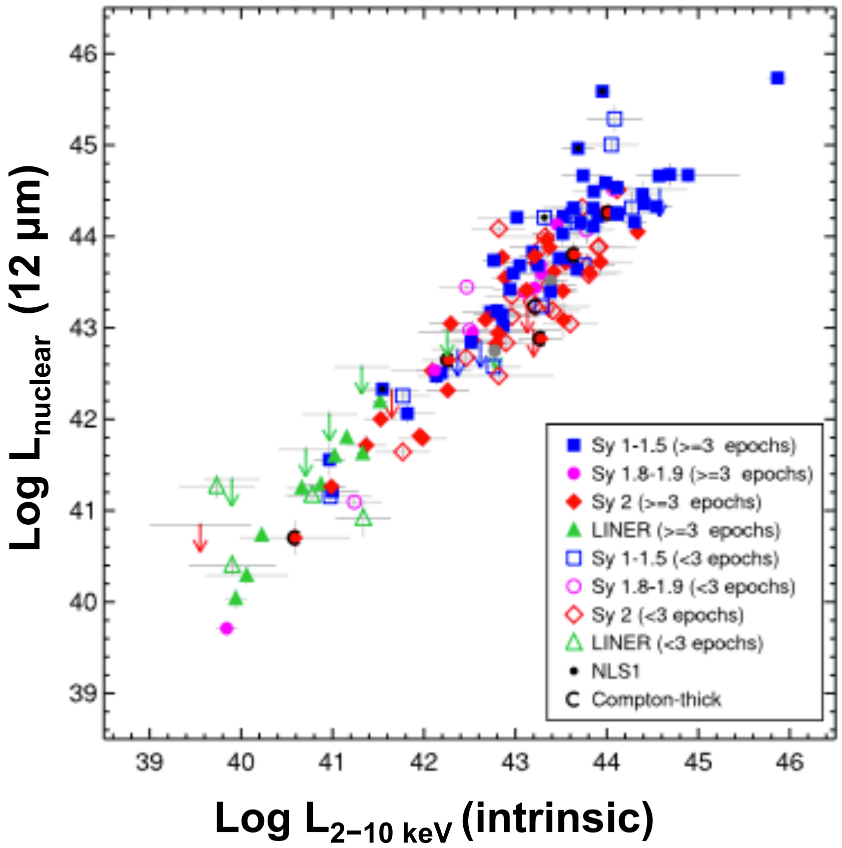
MID-IR excess galaxies (Daddi et al. 2007)



Mid-IR vs. X-ray emission of AGN

Asmus et al. (2014); see also Lutz et al. (2004) and Gandhi et al. (2009)





Corrected for the N_H

High mid-IR emission (from e.g. SED-fitting decomposition) coupled with low X-ray emission is suggestive of X-ray obscuration

MID-IR as a proxy of the intrinsic AGN strength

Multi-wavelength selection of AGN: pros and cons

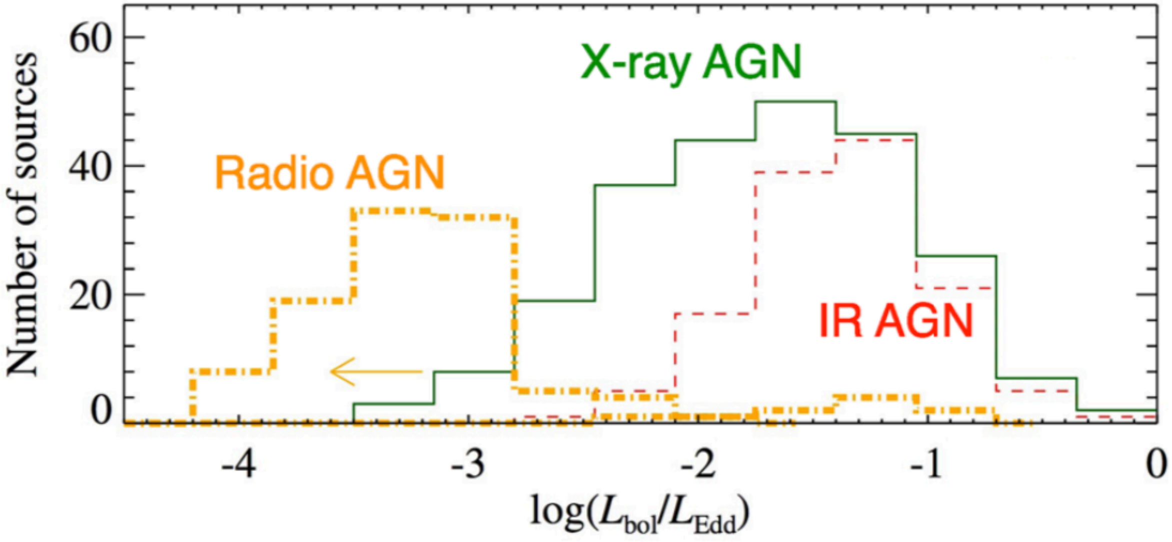
Table 3 A multi-wavelength overview of AGN highlighting the different selection biases (weaknesses) and key capabilities (strengths)

Band	Type	Physics	Selection biases/weaknesses	Key capabilities/strengths
Radio, $f_{\rm r} \gtrsim 1$ mJy	Jetted	Jet	Non-jetted sources	High efficiency, no obscuration bias
Radio, $f_{\rm r} \lesssim 1$ mJy	Jetted and non-jetted	Jet and SF	Host contamination	Completeness, no obscuration bias
IR	Type 1 and 2	Hot dust and SF	Completeness, reliability, host contamination, no dust	Weak obscuration bias, high efficiency
Optical	Type 1	Disk	Completeness, low-luminosity, obscured sources, host contamination	High efficiency, detailed physics from lines
X-ray	Type 1 and (most) 2	Corona	Very low-luminosity, heavy obscuration	Completeness, low host contamination
γ-ray	Jetted	Jet	Non-jetted, unbeamed sources	High reliability
Variability	All (in principle)	Corona, disk, jet	Host contamination, obscuration, cadence and depth of observations	Low-luminosity

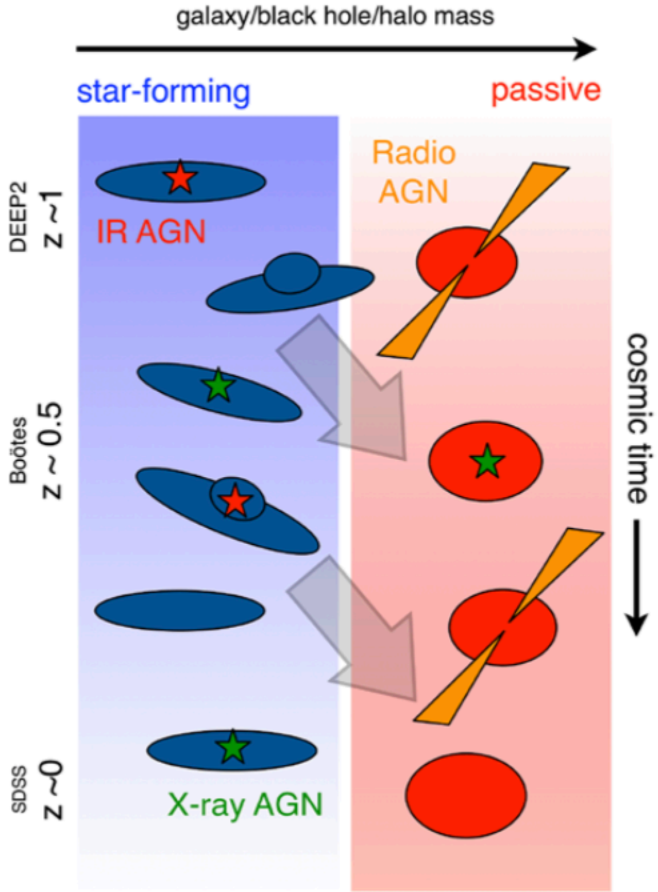
The definitions of some of the terms used in the bias and capability columns are as follows: *Efficiency*: ability to identify a large number of AGN with relative small total exposure times (this is thus a combination of the nature of AGN emission and the capabilities of current telescopes in a given band). *Reliability*: the fraction of sources that are identified as AGN using typical criteria that are truly AGN. *Completeness*: the ability to detect as much as possible of the full underlying population of AGN

from Padovani+17 review on AGN

A simplified picture of AGN evolution

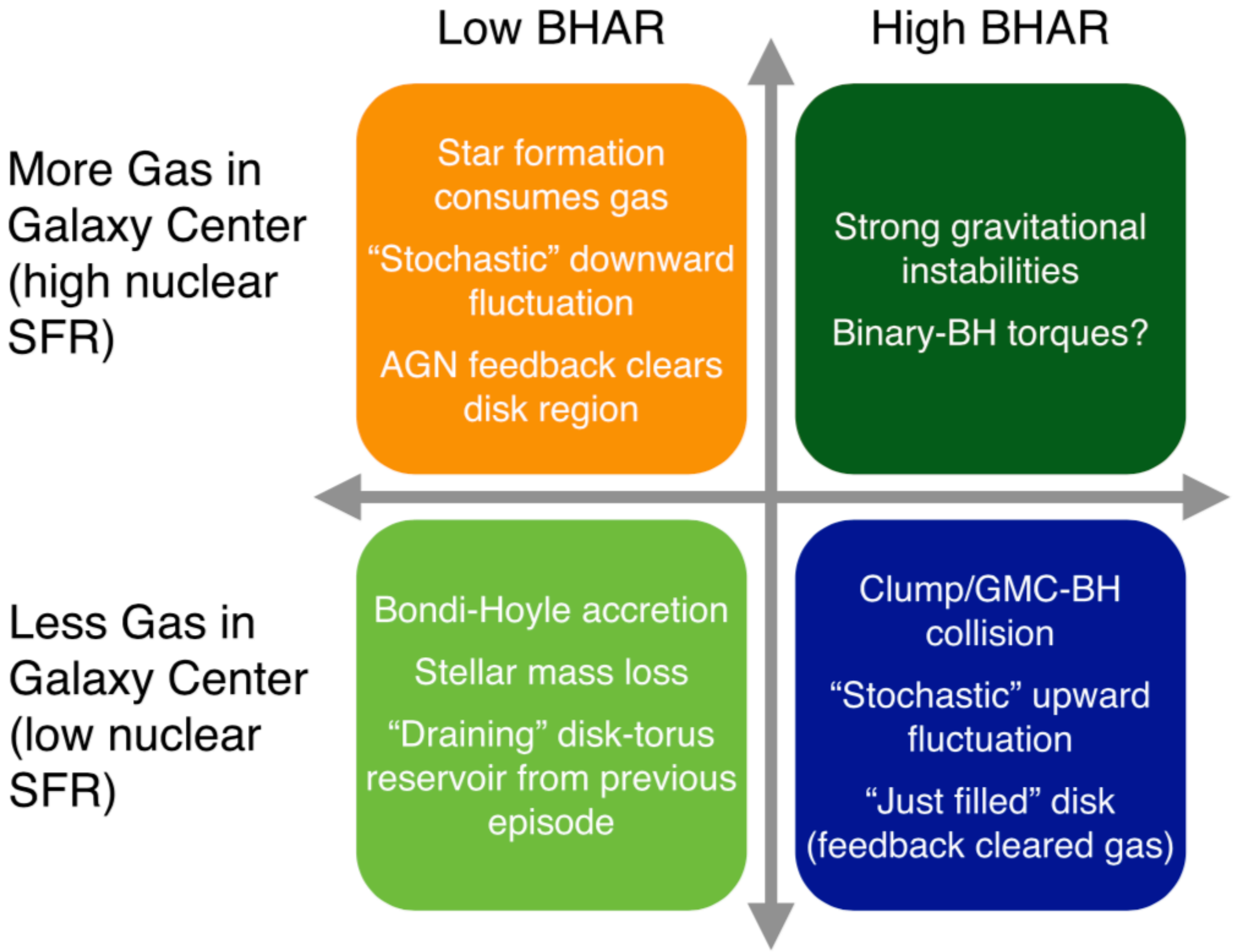


Hickox+09
situation up to z~1



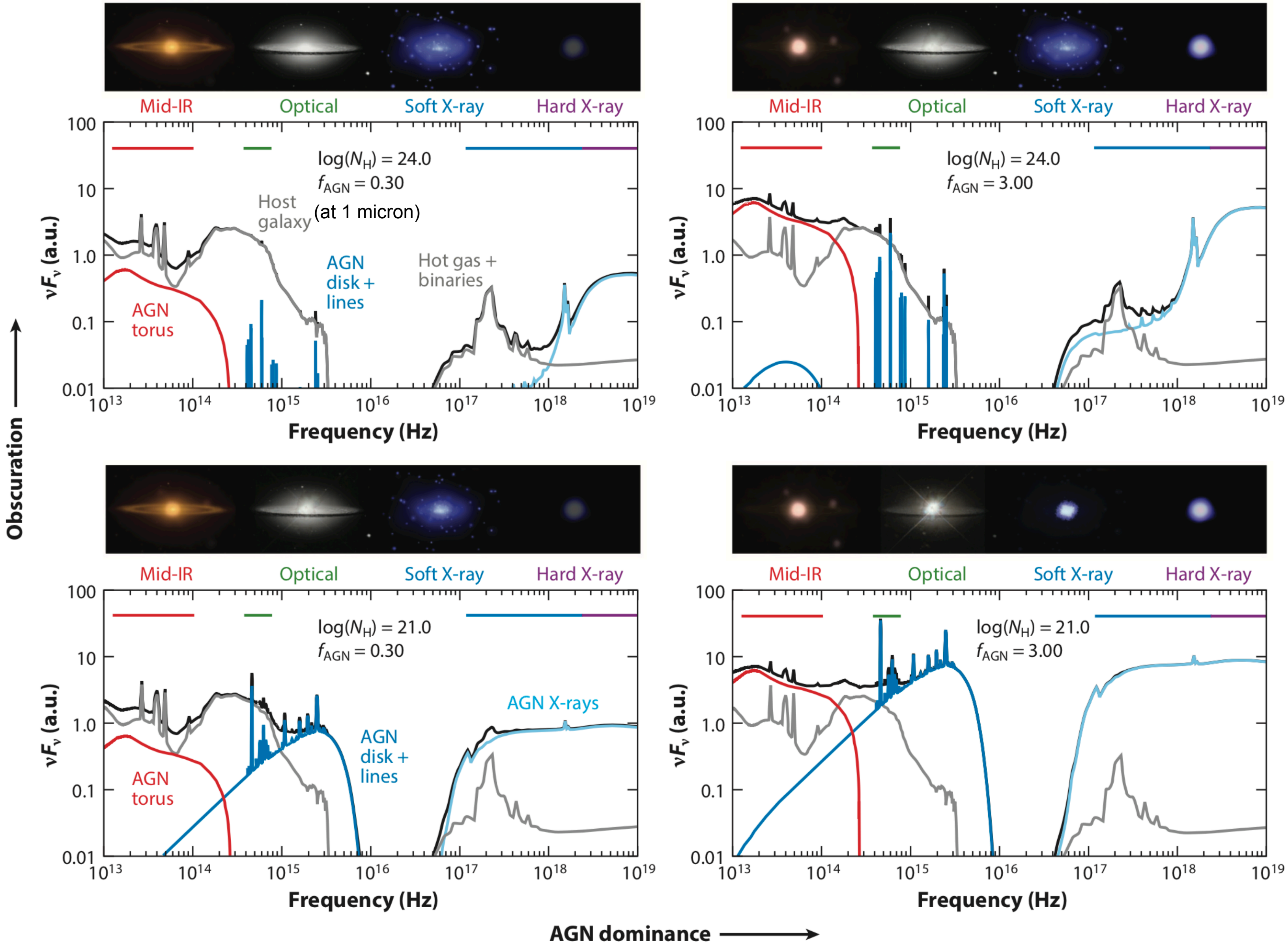
Goulding+14

- All galaxies appear to begin as star-forming blue-cloud systems and end as passive red-sequence sources, once their dark matter halos have grown sufficiently.
- Galaxies hosting **IR**, **X-ray**, and/or **radio** AGN appear to follow a similar evolutionary path: **radiatively efficient rapid BH growth** (IR/X-ray AGN) appears to be linked with those galaxies with large supplies of cool gas, while **mechanically dominated** (radio) **accretion** is associated with passive galaxies, which may also be responsible for preventing late SF.


Low BHAR
High BHAR
More Gas in Galaxy Center (high nuclear SFR)
Less Gas in Galaxy Center (low nuclear SFR)
Star formation consumes gas
“Stochastic” downward fluctuation
AGN feedback clears disk region
Strong gravitational instabilities
Binary-BH torques?
Bondi-Hoyle accretion
Stellar mass loss
“Draining” disk-torus reservoir from previous episode
Clump/GMC-BH collision
“Stochastic” upward fluctuation
“Just filled” disk (feedback cleared gas)

Padovani+17

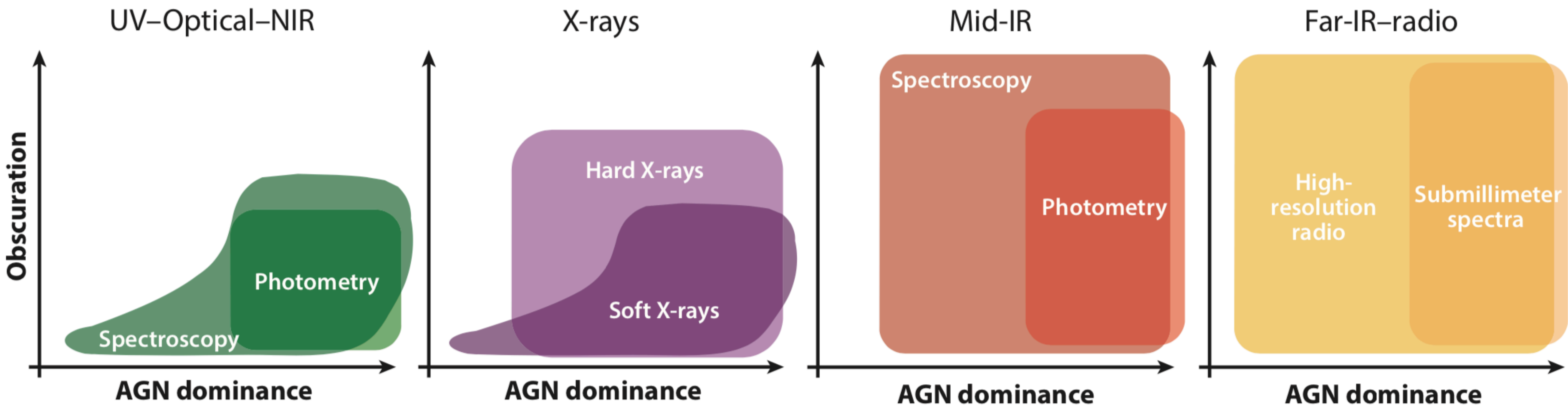
Multi-wavelength signatures of AGN



Hickox & Alexander 2018 (ARA&A)

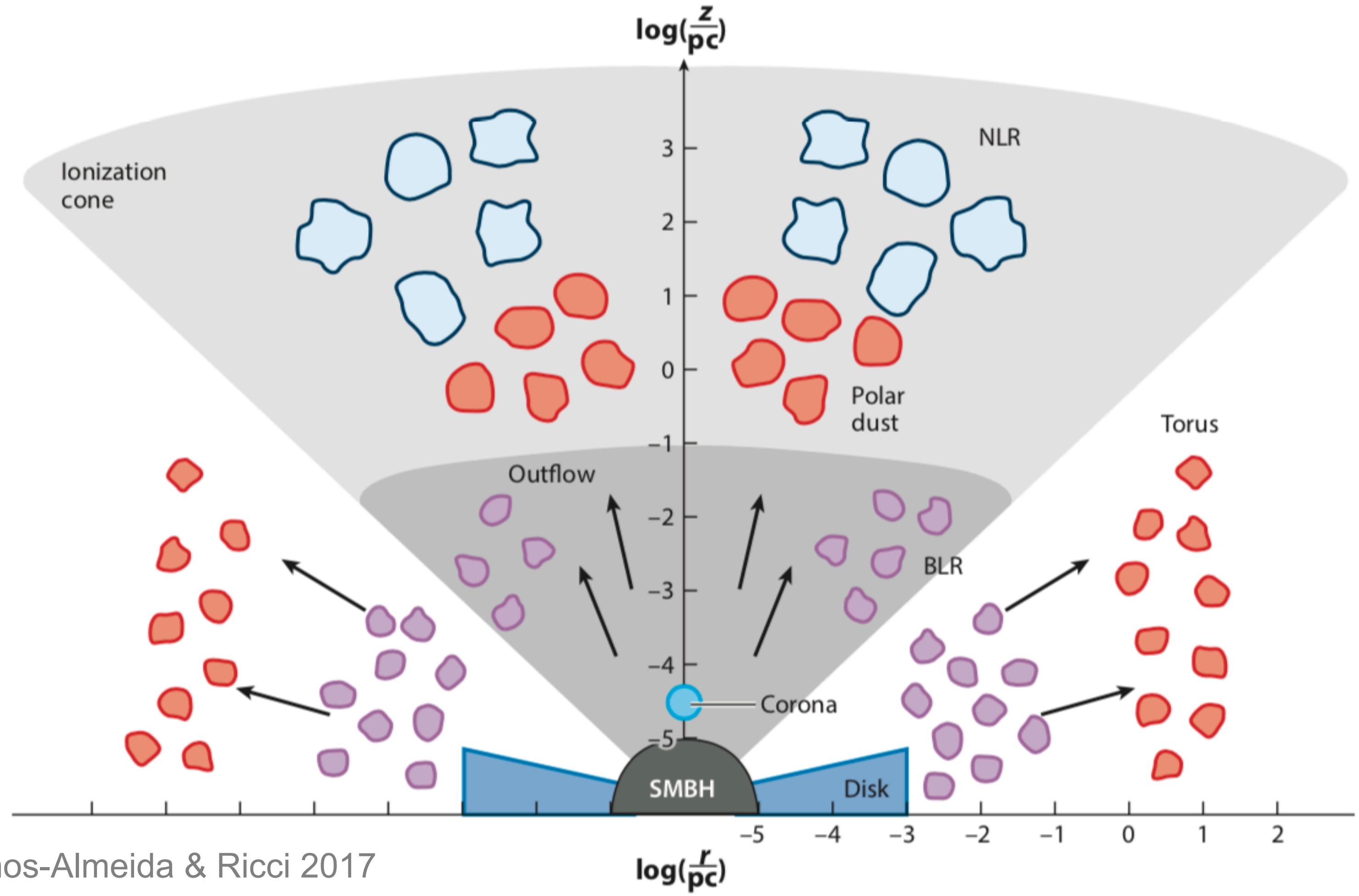
video at https://youtu.be/82LmtccFH7E

‘Optimization’ of AGN selection



Hickox & Alexander 2018 (ARA&A)

The final picture?



from Ramos-Almeida & Ricci 2017

The **absorber/reprocessing mater**ial is most likely **cloudy** and **filamentary** (e.g., Jaffe+04, Burtscher+13; Ramos-Almeida+11, Alonso-Herrero+, […])
Combes+18 – ALMA results, tori are disk-like on scales of ~10-30 pc + resonant rings at 100-pc scales; AGN non necessarily in the center

The quest for obscured AGN at different cosmic times

Obscured SMBH growth as a key phase in AGN/galaxy life

Needs for a ‘complete’ AGN census

X-ray surveys

- *Integral* and *Swift*/BAT surveys: limited sensitivity, mostly low z
- *NuSTAR*: more efficient and sensitive, obscured AGN up to z~3 (a few)
- Deep X-ray Surveys (*Chandra*, XMM): up to high redshift, limited by photon statistics

Combined mid-IR/opt/X-ray

- Mid-IR/optical extreme colors + X-ray spectroscopy/stacking
- Based on mid-IR as a proxy of the AGN strength
- Wide possibilities in the future due to a perfect combination of *SPICA* an *Athena* capabilities

Optical spectroscopy

- High-ionization narrow emission lines as proxies of the intrinsic nuclear emission
- $[\mathrm{OIII}]_{5007\text{Å}}$, $[\mathrm{NeV}]_{3426\text{Å}}$, $\mathrm{CIV}_{1549\text{Å}}$ selection in the optical
- Similar probes in the mid-IR: $[\mathrm{NeV}]_{14.3\mu m}$, $[\mathrm{OIV}]_{26\mu m}$ – matter for *SPICA* investigations at high redshifts

COMMON ULTRAVIOLET/OPTICAL/NEAR-INFRARED SELECTION CRITERIA FOR OBSCURED AGN

Commonly used criteria for identifying AGN in this waveband include:

- a high ratio of high-excitation to low-excitation emission lines;
- detection of very high-excitation emission lines (e.g., [NeV]); and
- UV, optical and/or near-IR colors characteristic of an AGN accretion disk.

Once AGN have been identified, common criteria for classifying the sources as obscured include:

- width of permitted emission lines $<1{,}000$ km s^{-1};
- high nuclear extinction from spectral analysis or multiwavelength SED fitting; a typical criterion is $A_V > 5$ mag; and
- weak UV/optical/near-IR emission compared to AGN luminosity identified in other wavebands (e.g., X-ray, mid-IR).

Hickox & Alexander 2018 (ARA&A)

COMMON X-RAY SELECTION CRITERIA FOR OBSCURED AGN

Commonly used criteria for identifying AGN in this waveband include:

- observed or intrinsic X-ray luminosity higher than expected for stellar processes (hot gas and X-ray binaries) in the galaxy; a typical criterion is soft (0.5–10 keV) $L_X > 10^{42}$ erg s^{-1}, which is sufficient for all but the most extreme host galaxies; and
- identification of an X-ray point source in high-resolution imaging of the nucleus of the host galaxy (for nearby galaxies, although note the caveats in Section 2.2).

Once AGN have been identified, common criteria for classifying the sources as obscured include:

- X-ray spectral fitting results implying $N_H > 10^{22}$ cm^{-2}, or equivalent measurements using X-ray hardness ratios;
- a low ratio of observed X-ray luminosity to intrinsic AGN luminosity (usually determined from IR or optical data); and
- a high equivalent width of the Fe Kα line.

Hickox & Alexander 2018 (ARA&A)

COMMON MID-INFRARED SELECTION CRITERIA FOR OBSCURED AGN

Commonly used criteria for identifying AGN in this waveband include:

- color diagnostics from mid-IR photometry;
- a significant contribution of AGN to mid-IR emission, from measurement of features in the mid-IR spectrum or fitting of AGN and galaxy templates to the mid-IR SED;
- detection of very high-excitation emission lines (i.e., [NeV], [NeVI]); and
- identification of a point source in high-resolution observations of a galactic nucleus (for nearby galaxies).

Once AGN have been identified, common criteria for classifying the sources as obscured include:

- red UV–optical–mid-IR photometric colors;
- high nuclear extinction (for example, $A_V > 5$ mag) from spectral analysis or optical/IR SED fitting; and
- detection of solid-state absorption features in the mid-IR spectrum (particularly the Si features at 9.7 and 18 μm).

Hickox & Alexander 2018 (ARA&A)

COMMON FAR-INFRARED–RADIO SELECTION CRITERIA FOR OBSCURED AGN

Commonly used criteria for identifying AGN in this waveband include:

- a significant AGN contribution from fitting of AGN and galaxy templates to the mid-IR–far-IR SED;
- a large ratio of high-excitation to low-excitation CO lines or the detection of dense gas tracers (i.e., HCN, HCO^+);
- a high observed radio power (i.e., $P_{1.4\ \mathrm{GHz}} > 10^{25}\ \mathrm{W\ Hz^{-1}}$);
- a flat radio spectral index; and
- an excess of radio emission beyond that predicted for star formation.

Due to low optical depth in the radio, most criteria to classify AGN as obscured rely on other wavebands after identification in the radio, but one technique is the detection of absorption from neutral hydrogen determined through the 21-cm line.

Hickox & Alexander 2018 (ARA&A)